A Software Program for the Analysis of Field Data from Photovoltaic Systems

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Abstract

A Software Program for the Analysis of Field Data from Photovoltaic Systems. Douglas Johnson (University of New Hampshire, Durham, NH) Keith Emery (National Renewable Energy Laboratory, Golden, CO 80401).

Researchers use software tools such as spreadsheets and graphing programs to help analyze collected data so that the data may be shared with the research community in a meaningful way. However, custom spreadsheets can be time-consuming to create and slow to execute when using large data sets. This project seeks to extend an existing software program written at the National Renewable Energy Laboratory (NREL) to enable the reading of data collected from ten photovoltaic test systems at NREL's Outdoor Test Facility. This paper discusses the assembly of the data, the steps used to create input routines for the data, and the output of the resulting program. The program uses a mathematical model from the Photovoltaics for Utility Scale Applications (PVUSA) project to predict power output based on irradiance, temperature, and wind speed and compares the prediction to actual measured power output. Six graphs show the output of the program for representative system. In addition, predicted power and the standard deviation between predicted and actual power are displayed for all ten systems with graphs showing the data set from inception to June 2002. This paper also briefly discusses the ease of extending this program to include additional models and graphs.

Research Category: Engineering

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Portions of this research may be submitted for publication

Introduction

To advance the state of the art in renewable energy, scientists from around the world must share their findings. Research papers provide a formal means of sharing information. E-mail and other informal discussions help disseminate information. Also, companies cite research in the literature they publish (see O'Neill, 2002, for an example). Before these discussions can take place, however, researchers must analyze and interpret data acquired through experimentation. To facilitate that interpretation, Keith Emery of the National Renewable Energy Laboratory (NREL), created a software program titled "Multiple Linear Regression" (MLR) to read collected data, filter it, and present graphs that aid researchers in interpretation. The goal of this summer intern project was to extend that software program, which could read data for one photovoltaic (PV) system, by adding the capability to read nine additional systems.

This task of data analysis can also be accomplished by individual researchers using a spreadsheet tool such as Microsoft® Excel®. However, this approach has several drawbacks. The process of creating individual spreadsheets with custom graphs and macros is time-consuming and the custom spreadsheets can be difficult to maintain. Each system has slightly different database formats, requiring a new spreadsheet for each system. Furthermore, large amounts of data can exceed Excel's worksheet capacity.

The MLR software addresses these issues by providing a consistent, easy-to-use, and easily extensible program for reading, displaying, and analyzing the large data sets recorded for systems at NREL. The program overcomes the drawbacks of custom spreadsheets mentioned above by providing a single code base that can be easily maintained and extended. Also, it is written once rather than being rewritten for every new set of data, thus reducing programming time. Furthermore, the program is capable of reading different database formats and translating them into a consistent format. Finally, it is capable of reading large data sets so that multiple years of data can be viewed at one time, possibly revealing trends that would be difficult to see otherwise.

The Outdoor Test Facility (OTF) at NREL collects large amounts of data from PV systems operating at the facility. These systems represent complete power production units such as those that might be installed at an end-user's site. Two of the ten systems mentioned in this report, SERF East and SERF West, produce power for the Solar Energy Research Facility (SERF) at NREL while being monitored for data collection (van Dyk, 1996). The set of plain text, tab-delimited databases for the ten systems used in this project occupies more than 260 million bytes of space.

The program that reads these data was created in National Instrument's LabVIEW, an application for data acquisition and analysis that is widely used in industry and research laboratories (reView, 1998). LabVIEW provides a graphical programming environment with a library of existing mathematical and programming tools. Non-programmers can quickly learn LabVIEW, yet it is amenable to professional programming standards that help create consistent and easily maintained program code.

The specific programming goals for this project were to

- Extend the existing MLR program to read data from nine additional system types with slightly differing field layouts
- Extract time, irradiance, power, temperature, and wind speed and format these fields in a consistent fashion

- Structure the data reading code so that new systems can be added by inserting one subroutine (subVI, in the language of LabVIEW) without disturbing the existing program.

Materials and Methods

Data

NREL's Keith Emery and Peter McNutt provided data files ranging in time from 1992 to 2002 for ten PV systems from three computer servers; see Table 1 for a list of systems and beginning data collection years. All of the data files were formatted as delimited plain text. However, some files used comma delimiters while others used tab delimiters. The program UltraEdit®-32 was used to search for and replace all commas in all files with tab characters; see Table 2 for a list of software tools used.

All data files for a particular system were concatenated using Microsoft Windows 2000 by issuing the command "`copy *.* systemname.tab`." The data files were then sorted by year, day, and time using UltraEdit-32.

This process resulted in large files containing duplicate data. The duplicate data derived from the fact that copies of the same file often resided on more than one of the three servers with multiple copies occasionally on the same server. To eliminate duplicates, the large data files were divided into individual files by year so that they could be opened in Microsoft Excel. These yearly files were then searched for duplicates using the "Advanced Filter, Unique records only" option in Excel. The results were saved as plain text tab-delimited files.

In the case of the systems named "CIS" and "USSC Roof," the format of the data files changed with the addition, removal, or rearrangement of fields. These changes are documented in Table 3. In some cases, data files contained out-of-place characters, such as End-of-File, or extra column separators. Often, End-of-Line characters were missing. These irregularities were found using a custom program written in Microsoft QuickBasic© that scanned for changes in column number. When changes were found, they were inspected in UltraEdit-32 and appropriate corrections were made. If a source of error was unclear or the reliability of a data point was uncertain, the data point (the row in question) was removed.

Programming

Programming consisted of several distinct phases, explained below.

One subroutine (subVI) was created for a representative system allowing user selection of data columns. This selection routine was written for the SERF East data set. The column headers for power were displayed under a power category so that the user could select AC or DC power. The program translated this selection to the appropriate column number and retrieved the data in that column for power. This was also done for irradiance, temperature, and wind speed. These four columns were then returned in a consistent format, along with date in seconds since 1904, to the main program for processing.

The result of this programming step was debugged and the user interface formatted to be consistent with the primary application graphical user interface, "Front Panel" in LabVIEW terminology. The SERF East subVI was tested with sample data and the user interface was formatted to a final state so that this selection subVI could be used as a template without aesthetic or major functional modification.

A copy of this subVI was created for each of the remaining nine systems and modified as needed for each system database format. Specifically, the names under each category were changed to match the column headings for each system. For example, DC Power is labeled as "DC_P," "DC_POW," or "DC_Powe," depending on the system (Table 3 has a comprehensive list). Also, each system may have the same data in different columns. For example, DC power is usually column four but may be column five or six for some systems. Therefore, column numbers were changed for each system to access the correct data.

The completed subVIs were tested by reading sample data sets for each system type. Optimizations were made to improve speed and memory handling.

The front panel of the main program was evaluated for consistency of appearance and operation with the subVIs and was modified where necessary. Formatting changes were also made based on recommendations from Keith Emery.

Testing was repeated with the completed operating program by loading complete data sets (from inception to final entry) for every system type. Each front panel control was operated to verify proper functioning.

The PVUSA (Photovoltaics for Utility Scale Applications) model was used to estimate power production at user-selectable power rating test conditions (PTC) (Whitaker, 1997).

The PVUSA regression equation is,

$$P = C_1*E + C_2*E^2 + C_3*E*T,$$

where

P	=	Power output, kW DC or kW AC
E	=	Irradiance
T	=	Temperature
$C_{1\text{-}3}$	=	Coefficients obtained from regression fit

This equation is implemented via the code displayed in Figure 2, “Model Fit Code.”

Results

Figures 5a through 14c show the results of running the completed software. They display the output for each of the ten systems using the complete data sets. Each figure shows a number of important pieces of information. In particular, PTC, fit coefficients, filter settings, and a graph are presented. In addition, the overall power rating based on the calculated fit coefficients and PTC is displayed, and the standard deviation from this value is shown.

Every set of figures contains one figure displaying the entire unfiltered data set. The next figure in each set shows the data with filter settings adjusted for irradiance and power. When AC and DC power are distinguished in the data, an additional figure shows filtered data with AC power.

Figures 7a and 7b differ slightly from the others. They show the use of the PVUSA equation containing a term for wind speed (Whitaker, 1997). This execution of the software used the Entech 189 data set. It contains wind speed data and falls under the system category "OCIV," which is a Fresnel lens outdoor concentrator test bed (O'Neil, 2002). Because this is a concentrator system, PTC irradiance is adjusted to 850W/m^2.

Discussion

Program Output

The section of the program that accepts user input and displays results is shown in Figures 1a through 1c. The portion of the front panel shown in Figure 1a displays the results of selecting the APS Delta Tracker system with data files from 1996 to 2002. In this example, the PVUSA equation excluding wind was used as shown under the Formula Selector as P(E,T). The resulting fit coefficients are displayed to the right above the graph. The power rating for this system was calculated using these coefficients and a PTC of 1000 W/m^2 irradiance, 20°C temperature, and 1 m/s wind speed (wind speed is set but not used for this equation). In addition, the standard deviation, based on the difference between the fit values and the measured power values, is displayed. The equation for this value is:

$$\sqrt{\frac{\sum_{i=1}^{n}(F_i - M_i)^2}{n}} \quad \text{(National Instruments, 2000)}$$

where F is the fit values, M is the measured values and n is the number of points. The regression formula and the PTC are user selectable.

Below this information, slider bars for filtering options are displayed. In this example, irradiance values are set to the program's maximum of 1500 and minimum of 0. Temperature is set to the actual measured maximums and minimums; AC power is set to the maximum measured value, with a minimum of 10% of that value. There is no wind speed in this data set, and the date filter is set to the measured maximum and minimum values. Below the Filtering Options box, the number of unfiltered data points is displayed to the right. To the left, the number of points after filtering is displayed. The number of filtered points is substantially lower than the number of unfiltered points. Data collection is continuous, and the unfiltered data include points at night when no power is produced; therefore, filtering based on power excludes this large number of data points.

On the lower right of the screen, a graph is displayed. It shows the calculated power based on the PVUSA regression fit (marked with a plus symbol) and the actual measured power (marked with a circle). The graph is difficult to read at individual points because approximately seven years of data are displayed simultaneously. However, this view shows overall trends. In addition, the tools on the lower left corner of the graph that appear as a hand and a magnifying glass allow the graph to be manipulated, showing smaller segments of the graph in greater detail.

Figure 1b shows three more graphs from the front panel. Again, values from the PVUSA regression fit are marked with a plus, and actual measured values are marked with a circle. In this example, more than 45,000 data points are displayed, again making individual points difficult to see. These graphs may also be manipulated to show smaller segments, as described above. Two data tables are also shown in Figure 1b. These tables display the unfiltered data. Any point in the data set can be reached by typing an index number into the top left box.

Figure 1c shows the final screen of the front panel. This portion displays two more graphs that show the ratio of the best fit power values divided by the measured power values over a range of irradiance and temperature. The graphs function as described above. The irradiance graph shows that the modeled and measured values generally converge as irradiance increases, indicating that the PVUSA model tends to be more accurate at higher irradiance levels. The temperature graph does not show a similar relationship.

It should be noted that all of the graphs described above and the PVUSA regression and fit code existed before the software development for this summer project began. The scope of this project was the expansion of the data reading routines.

Program Code

Figure 2 shows the LabVIEW code for the PVUSA fit. On the left, measured values for irradiance, temperature, and wind are multiplied according to the equation:

$P = C_1E + C_2E^2 + C_3E*T + C_4E*S$ where:

P	=	PV system output, kW DC or kW AC
E	=	Irradiance
T	=	Temperature
S	=	Wind Speed
C_1-C_4	=	Fit Coefficients (to be determined)

These data are combined in an array and processed, with measured powers, using the LabVIEW library math function "General Least Squares Linear Fit". The output of this function is an array of fit power values and the coefficients corresponding to C_1 through C_4 in the PVUSA equation above.

The overall power rating for the system is calculated as shown in Figure 3 using the (PTC settings as selected on the front panel and the calculated fit coefficients. The code fragment shown in Figure 3 expresses the equation given above in a slightly different form:

$$P = (C_1 + C_2E + C_3*T + C_4*S) * E.$$

Conclusion

The author has stated that LabVIEW programs are easily extensible. Figure 4, which shows the code required to produce the graph displayed in Figure 1a, provides an example of this extensibility. The fairly complicated PVUSA model fit vs. time graph consists of just three inputs, two bundle functions, one build array function, and the plot function. The simplicity of this code illustrates the ease with which additional features, such as new graphs, can be added as researchers consider new ways of viewing data. With the addition of the input routines, which was the objective of this project, a new piece of code can quickly be run with data from ten different systems. Furthermore, as new systems are added, additional input routines can be inserted without disturbing existing code. Thus, the program increases the number of systems that may be viewed and reduces the amount of time researchers must devote to custom programming.

Future modifications could include adding new mathematical models or the modifying existing models, allowing the accuracy of their predictions to be assessed. Improving the accuracy of models could aid the PV community by increasing the confidence of producers, installers, and customers in PV system power ratings. Using this program and the large amount of data that it can read, researchers may be able to test new models fairly quickly.

Acknowledgements

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Finally, thanks also to Peter McNutt for his time and assistance in gathering the data that is a foundation of this project, Peter Faletra for sharing his vast experience, and the numerous other researchers at NREL who gave their time to help instruct all the summer interns.

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Whitaker, Charles M., Townsend, Timothy U., Newmiller, Jeffrey D. (September). "Application and Validation of a New PV Performance Characterization Method." Paper presented at the 26th IEEE Photovoltaic Specialists Conference, Anaheim, California, September.

Tables and Figures

Table 1. Description of PV systems at NREL.				
System	**Manufacturer**	**Technology**	**Rating**	**First Year**
APS[1]	Advanced Photovoltaic Systems	a-Si	1.5kw	1996
ASE[4]	ASE Americas, Inc.	EFG-Si	1.4kw	1995
CIS[2]	Siemens Solar Industries	CIGSS: $Cu(In,Ga)(Se)_2$	1.0kw	1994
Entech 189	ENTECH	mono-Si	.86kw	2002
USSC Roof[1]	United Solar Systems Corporation	triple junction a-Si	1.0kw	1994
SCI1[5]	Solar Cells Inc.	CdTe	1.0kw	1995
SERF East[3]	Siemens Solar Industries	mono-Si	6.0kw	1995
SERF West[3]	Siemens Solar Industries	mono-Si	6.0kw	1995
SOLR[1]	Solarex	a-Si/a-Si:Ge	1.0kw	1995
USSC[1]	United Solar Systems Corporation	a-Si/a-Si	1.8kw	1992
1 – Kroposki, 1997. 2 – Strand, 1996. 3 – van Dyk, 1996. 4 – McNutt, 2002. 4 – Kroposki, 1996.				

Table 2. Programming tools summary.
SOFTWARE TOOLS USED:
IDM Computer Solutions Inc. UltraEdit-32 version 9.10
Microsoft Excel version 9.0.3821 SR-1
Microsoft QuickBasic version 4.5
Microsoft Windows 2000 version 5.00.2195
National Instruments LabVIEW 5.1
National Instruments LabVIEW 6.0.1
HARDWARE TOOLS USED:
Apple Macintosh G3 PowerPC
Dell Inspiron 8000

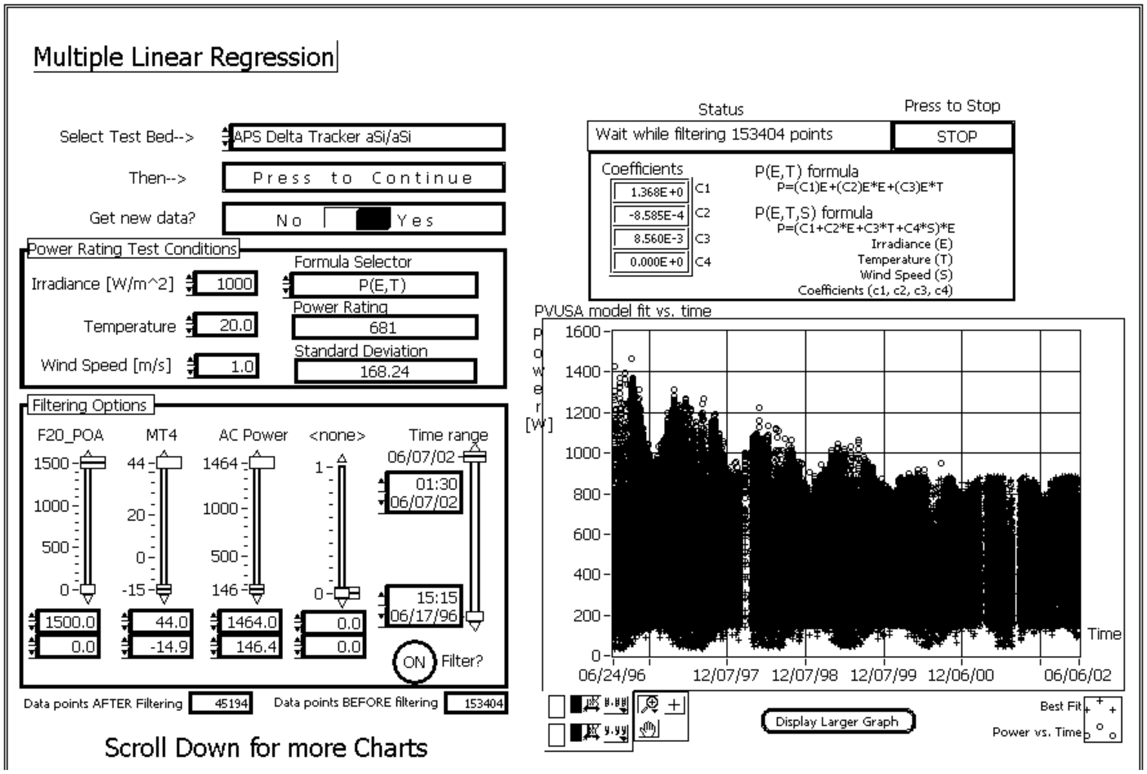

Figure 1a. Main Front Panel, screen one.

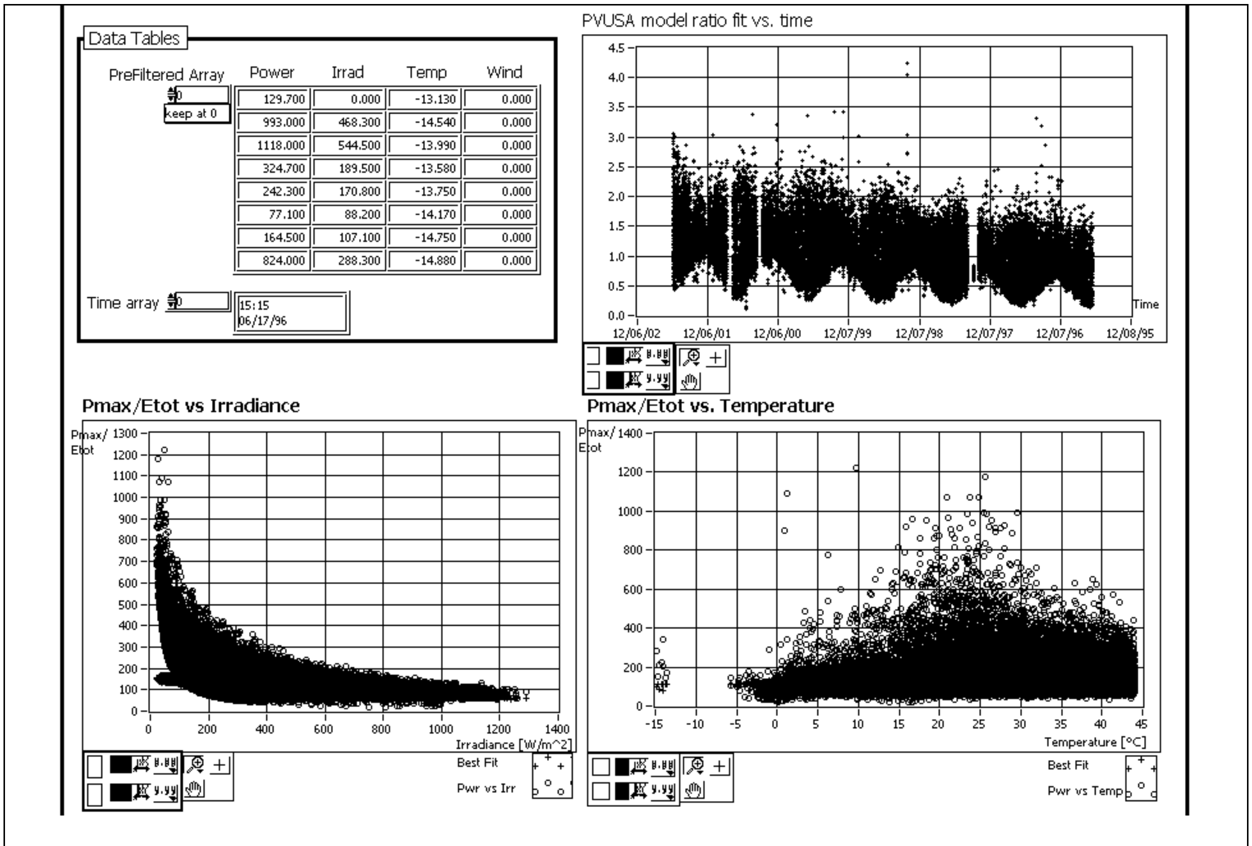

Figure 1b. Main Front Panel, screen two.

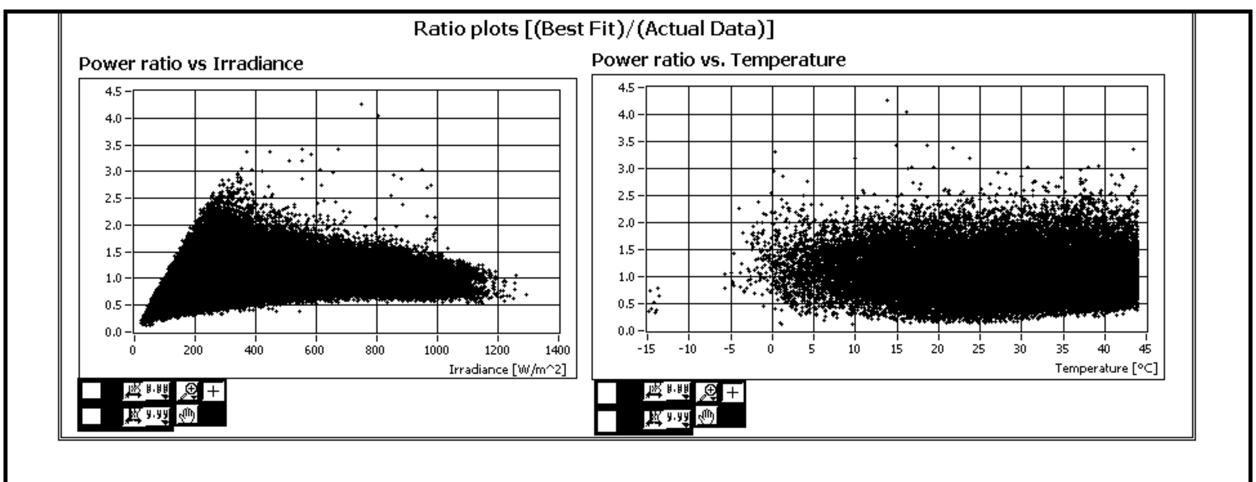

Figure 1c. Main Front Panel, screen three.

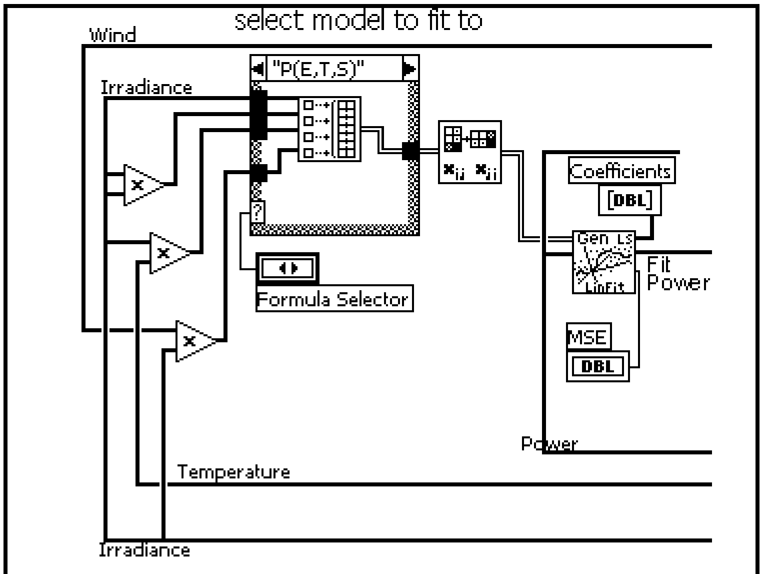

Figure 2. Model fit code.

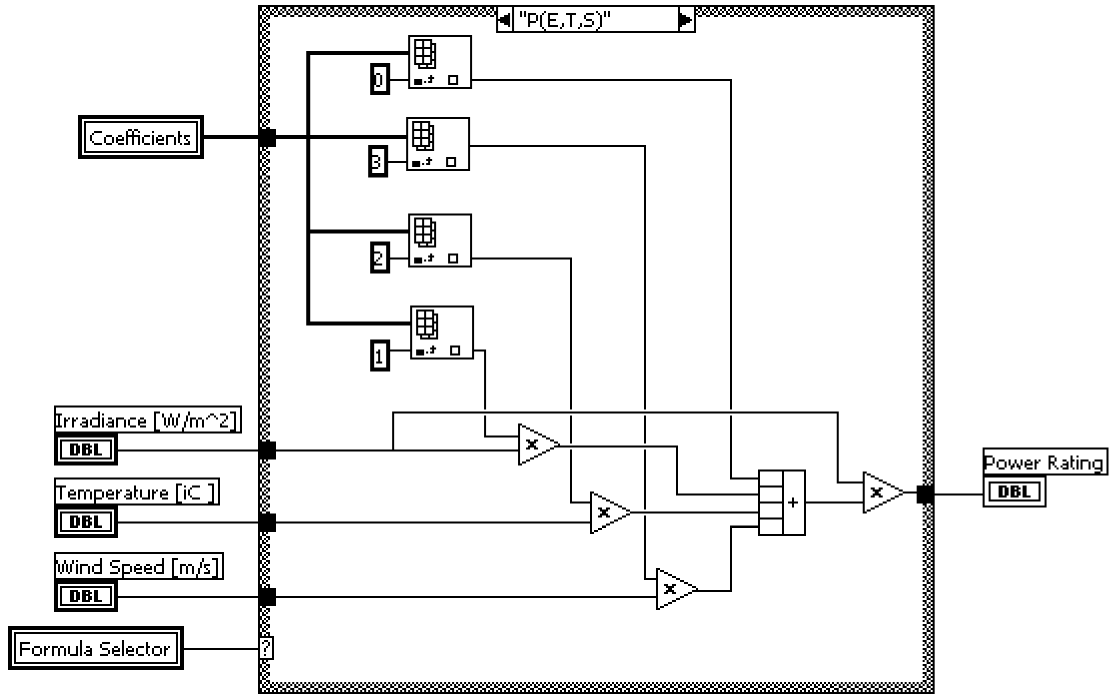

Figure 3. Power rating calculation code

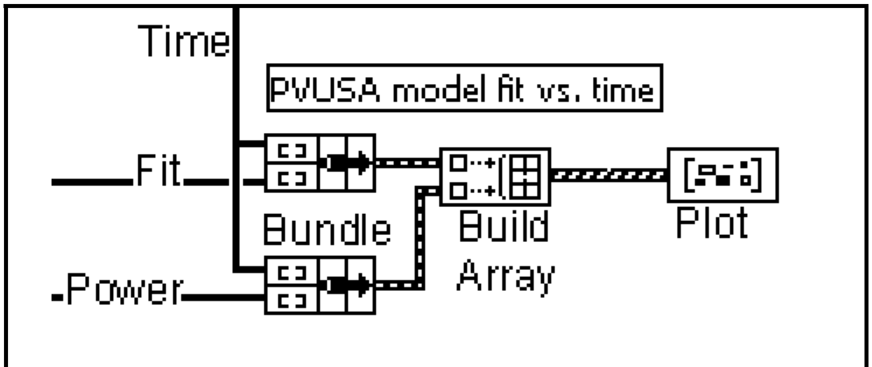

Figure 4. PVUSA model fit vs. time graph code.

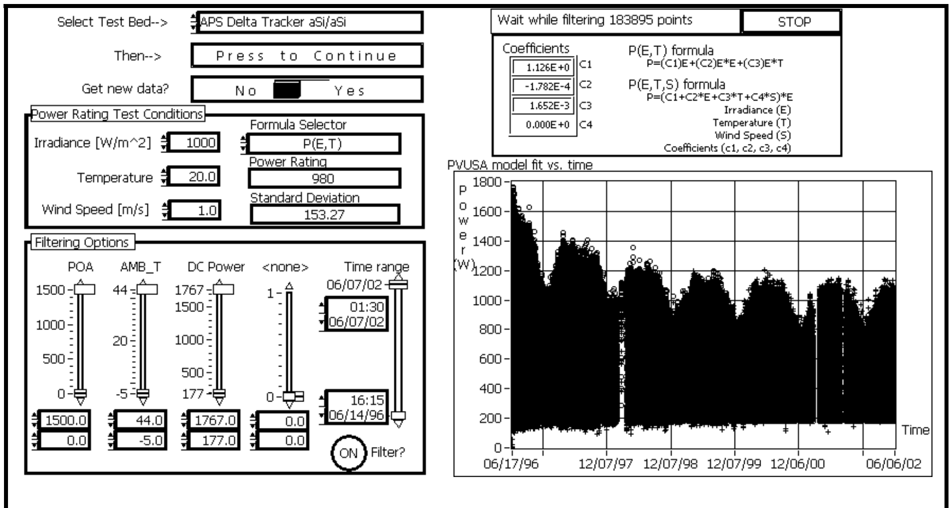

Figure 5a. APS unfiltered DC power.

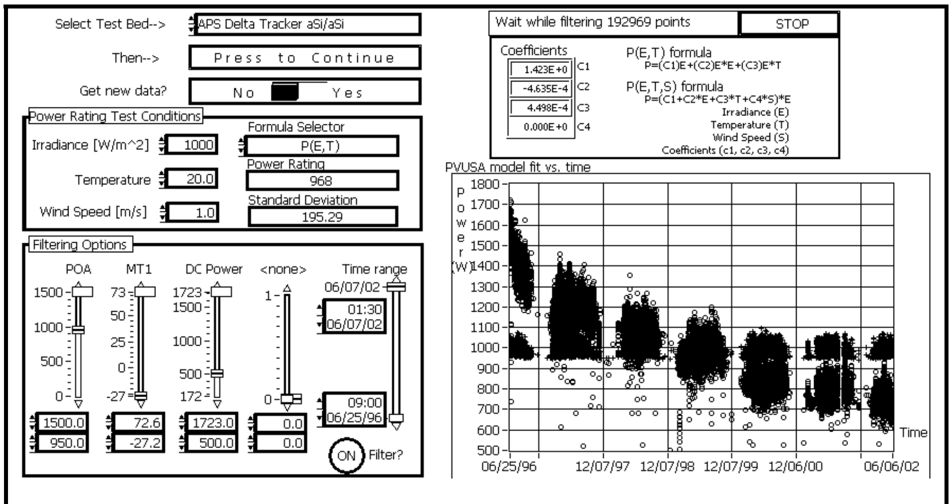

Figure 5b. APS filtered DC power.

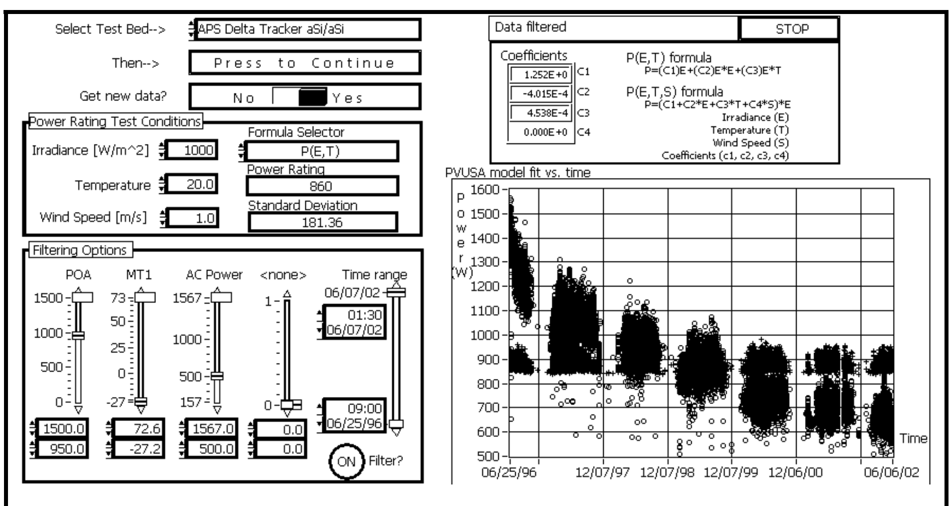

Figure 5c. APS filtered AC power.

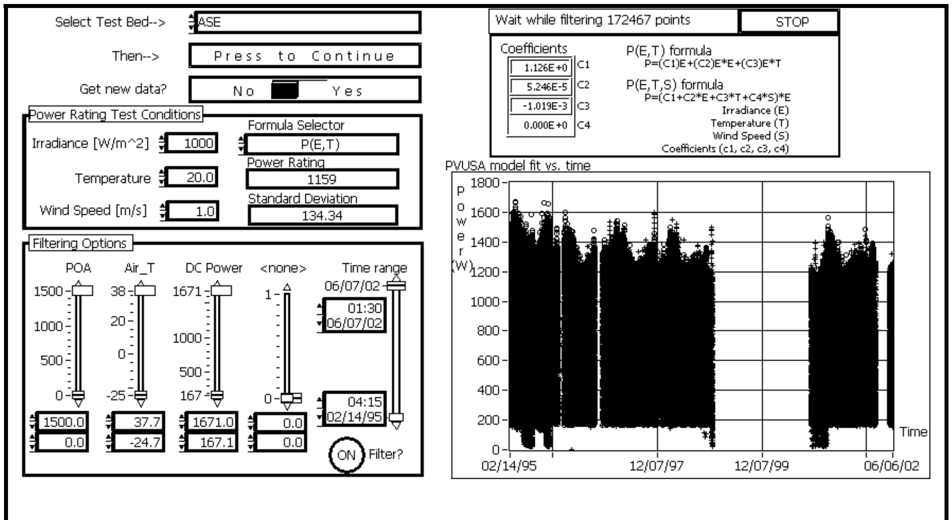

Figure 6a. ASE unfiltered DC power.

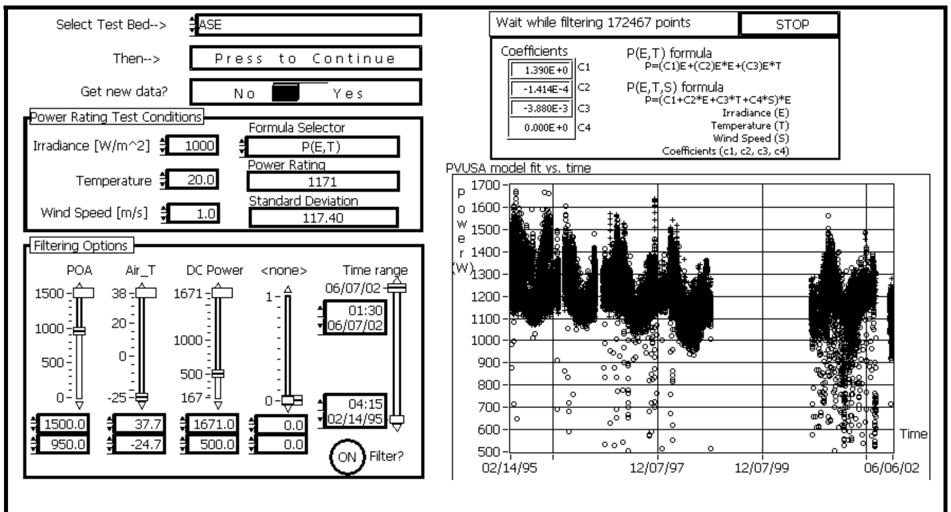

Figure 6b. ASE filtered DC power.

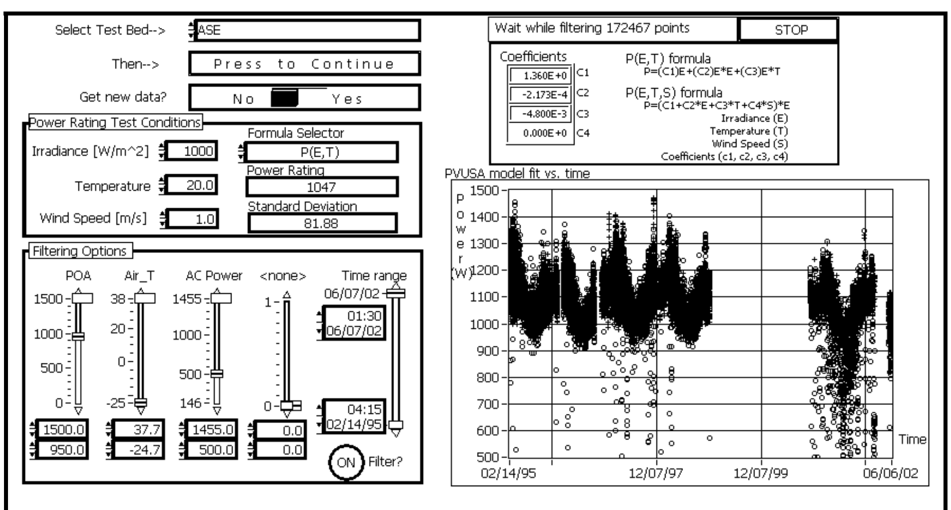

Figure 6c. ASE filtered AC power.

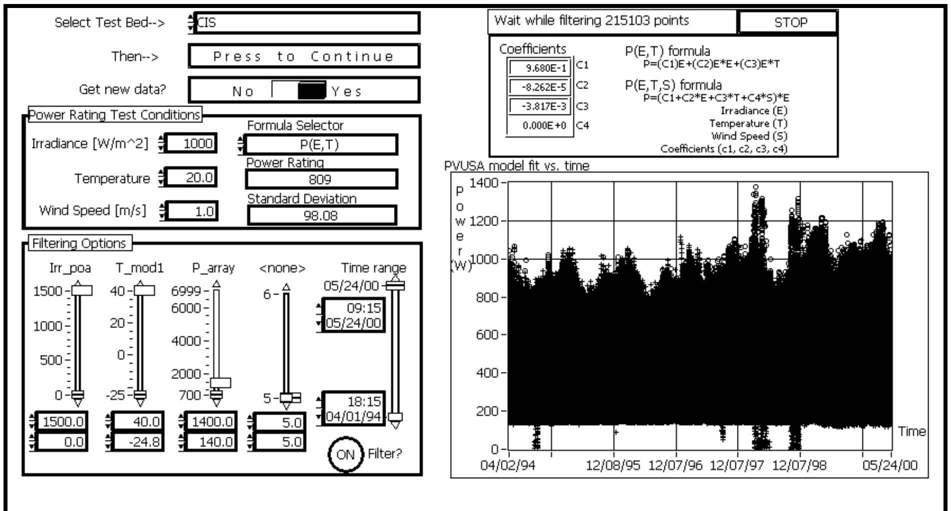

Figure 7a. CIS Unfiltered

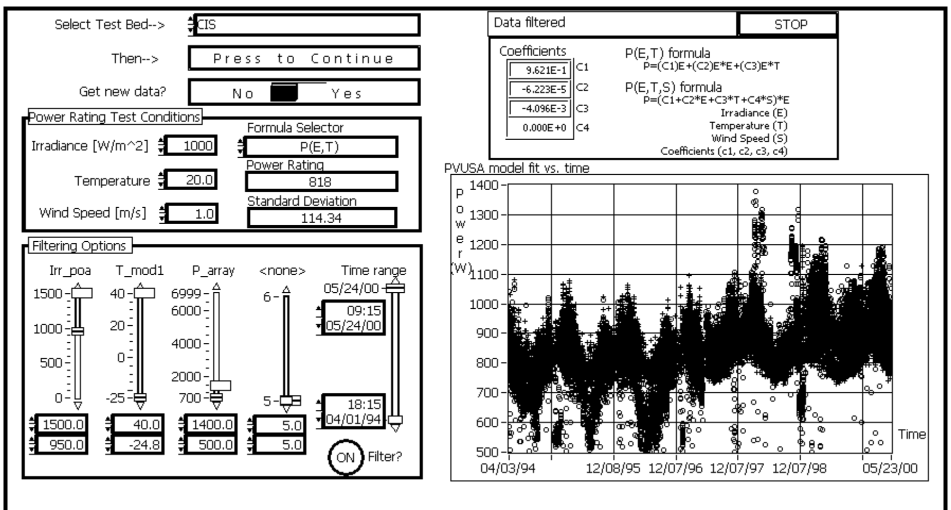

Figure 7b. CIS Filtered

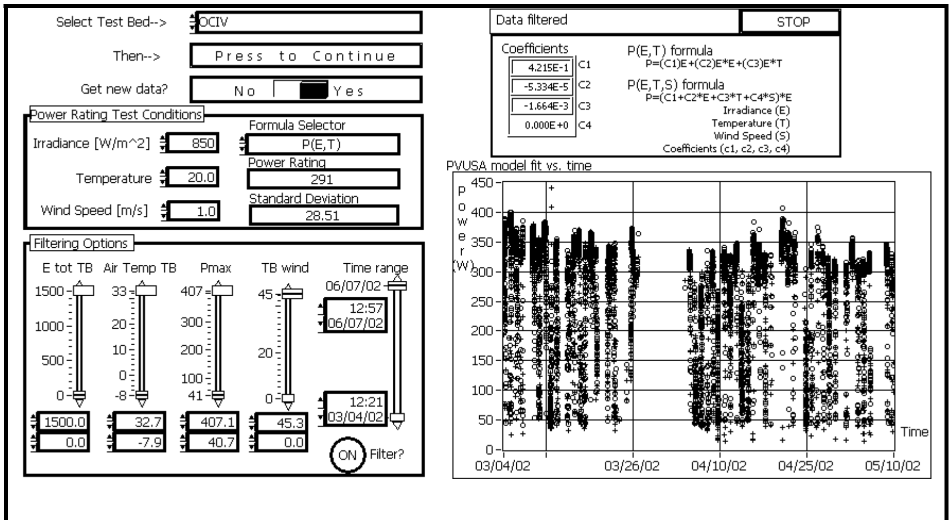

Figure 8a. Entech 189 Unfiltered

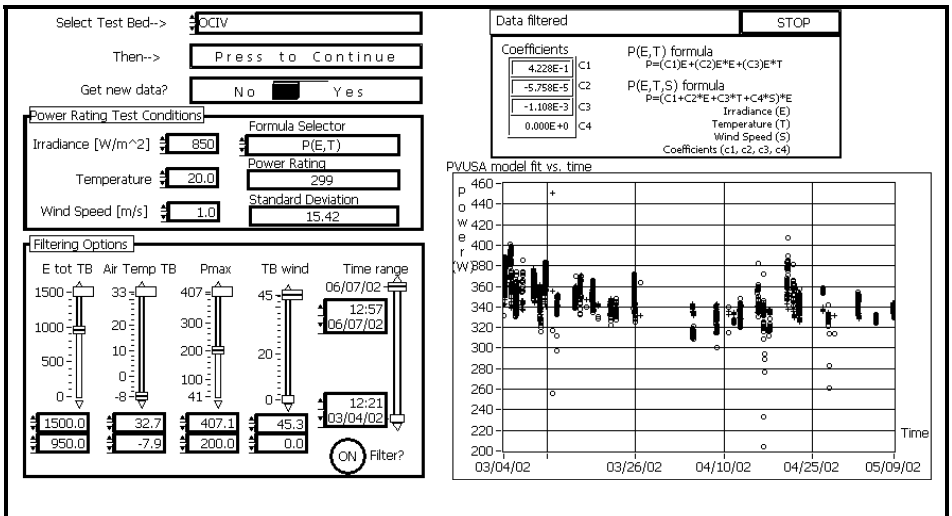

Figure 8b. Entech 189 Filtered

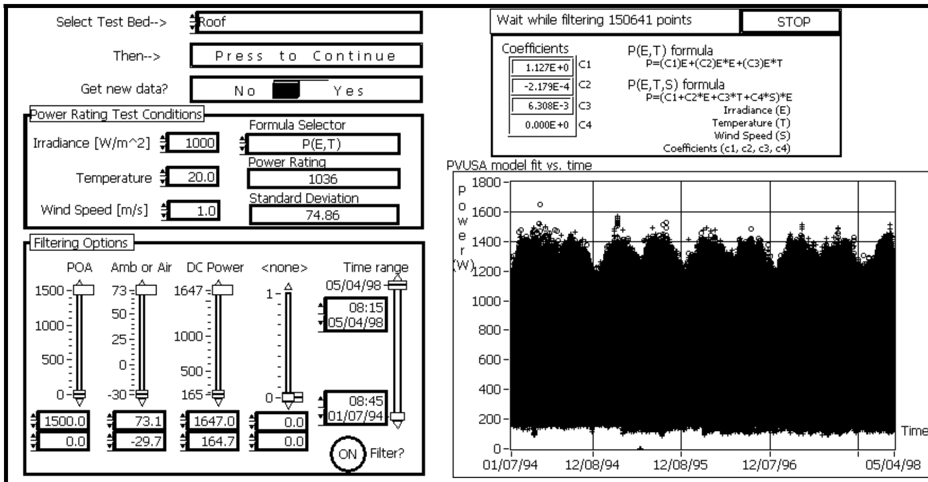

Figure 9a. USSC Roof unfiltered DC power.

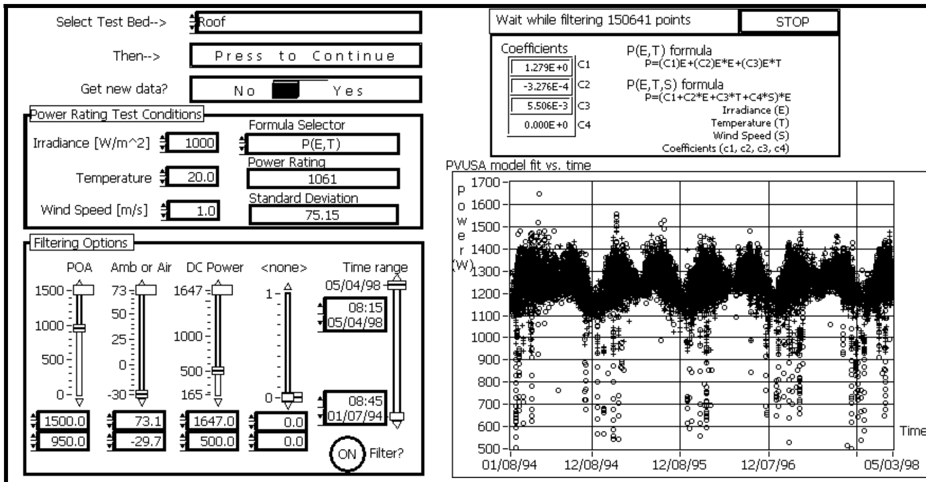

Figure 9b. USSC Roof filtered DC power.

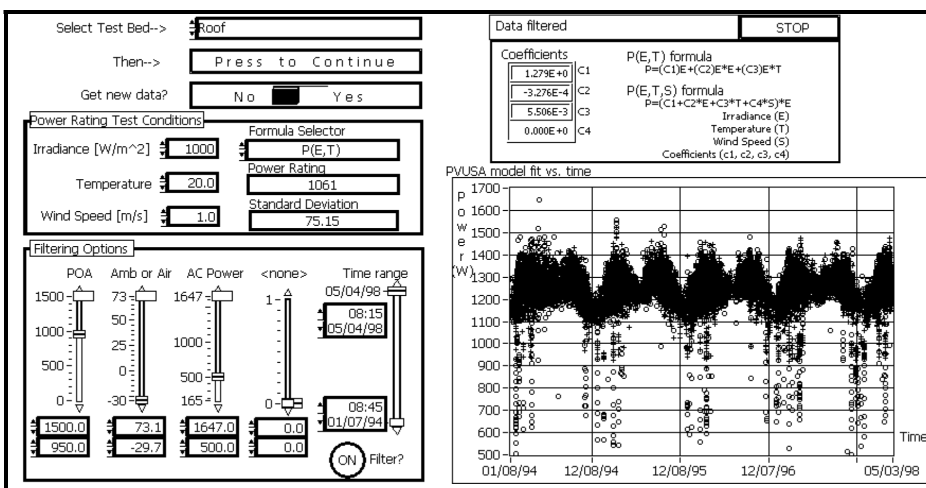

Figure 9c. USSC Roof filtered AC power.

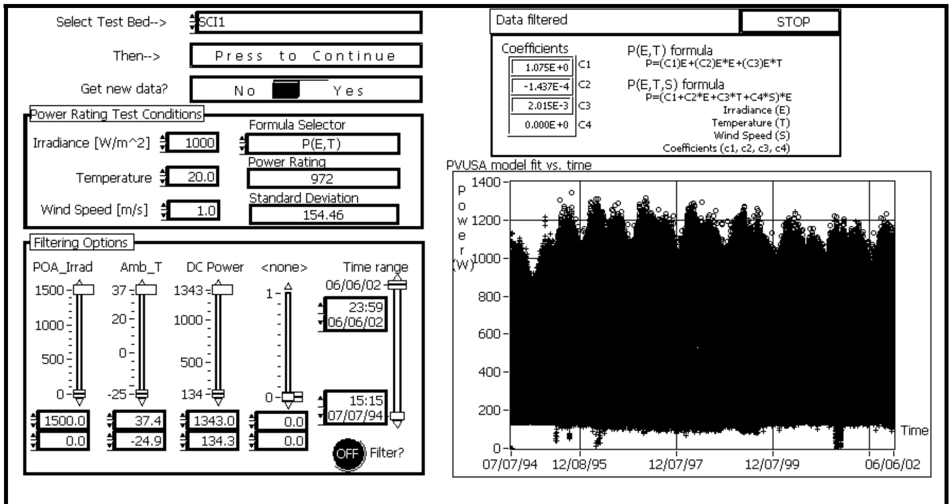

Figure 10a. SCI1 unfiltered DC power.

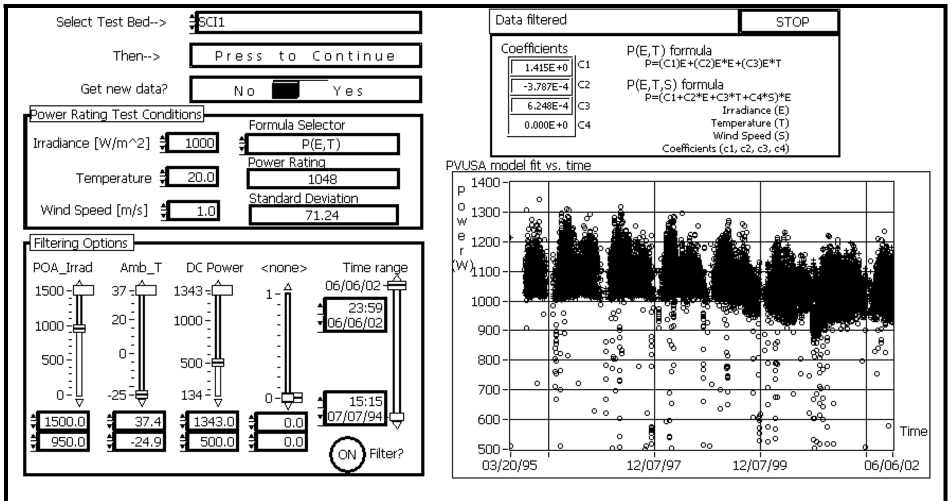

Figure 10b. SCI1 filtered DC power.

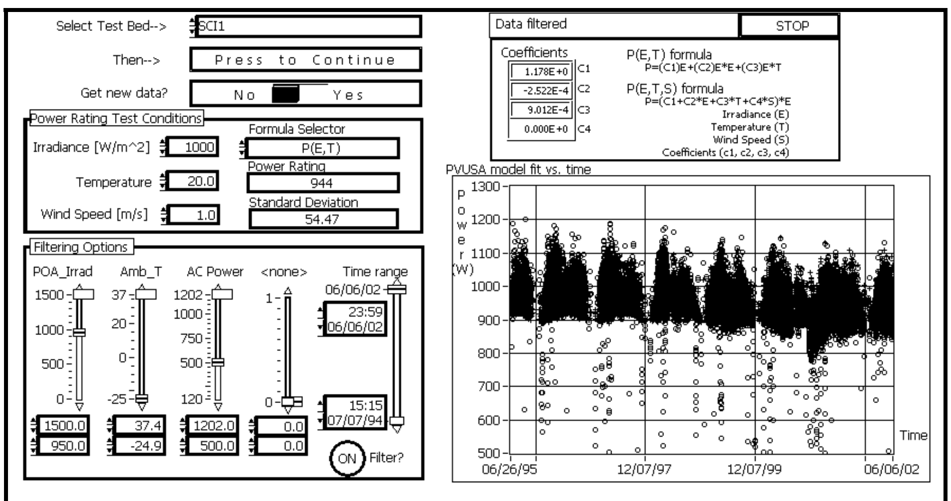

Figure 10c. SCI1 filtered AC power.

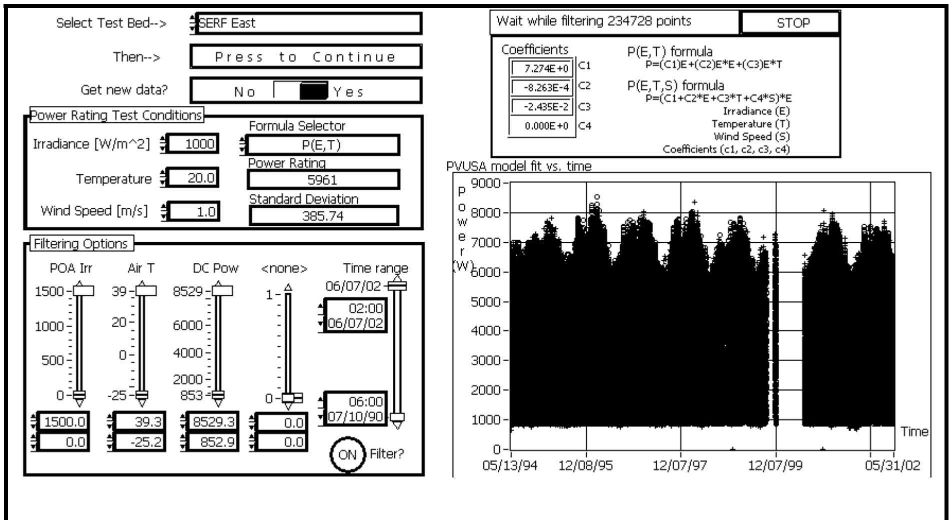

Figure 11a. SERF East unfiltered DC power.

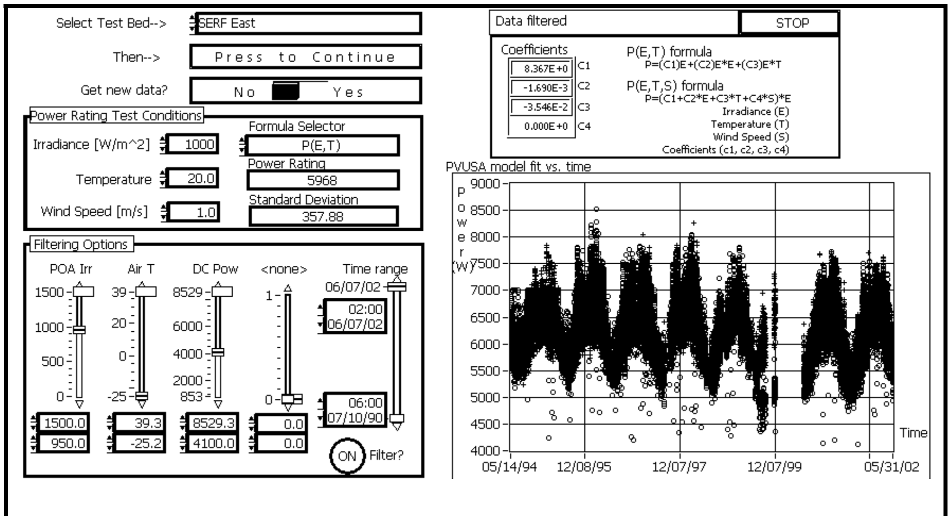

Figure 11b. SERF East filtered DC power.

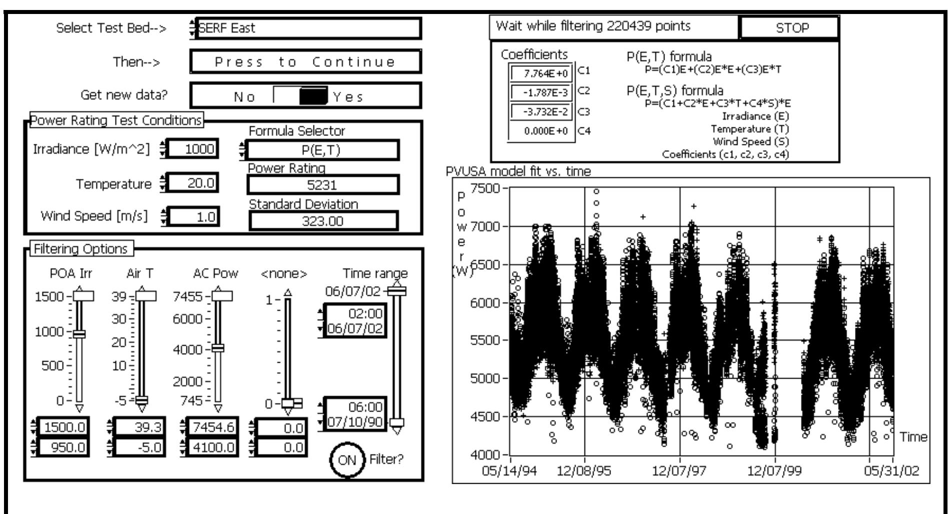

Figure 11c. SERF East filtered AC power.

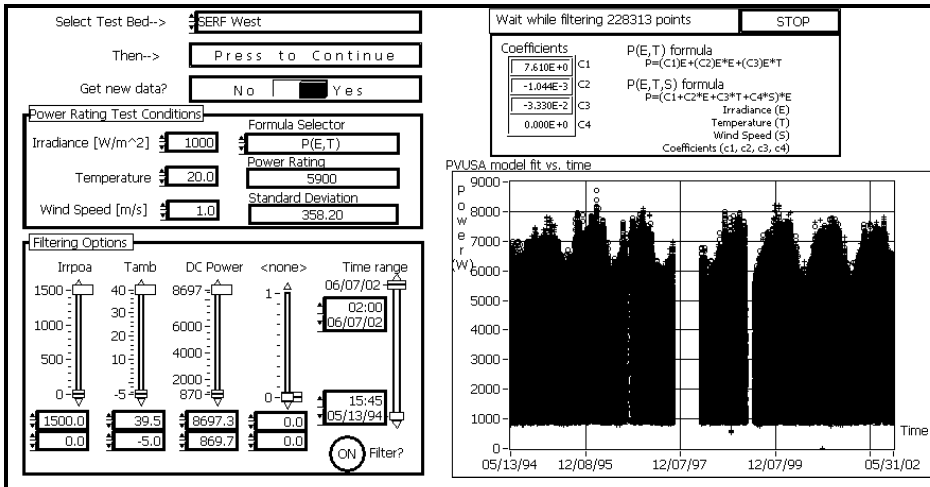

Figure 12a. SERF West unfiltered DC power.

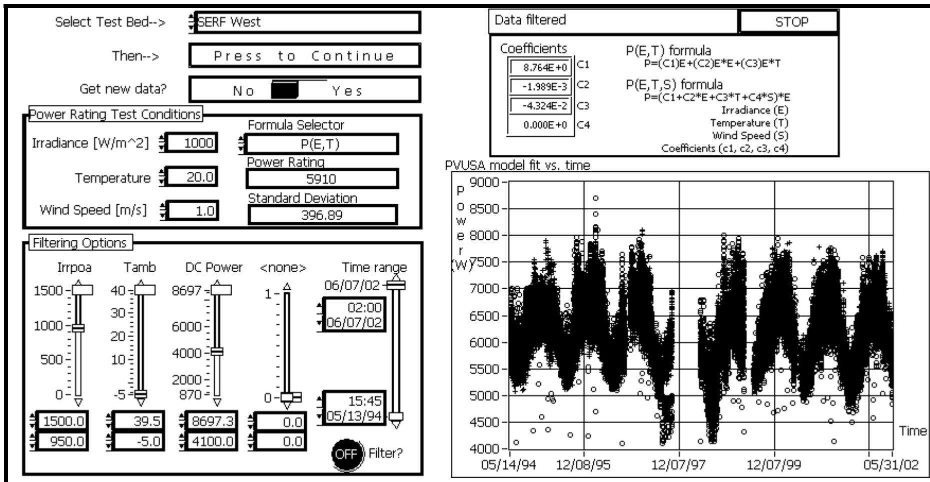

Figure 12b. SERF West filtered DC power.

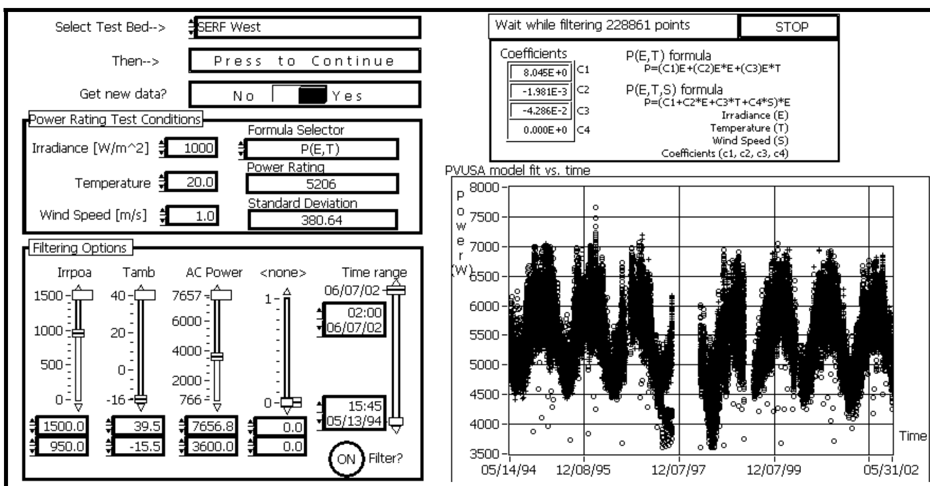

Figure 12c. SERF West filtered AC power.

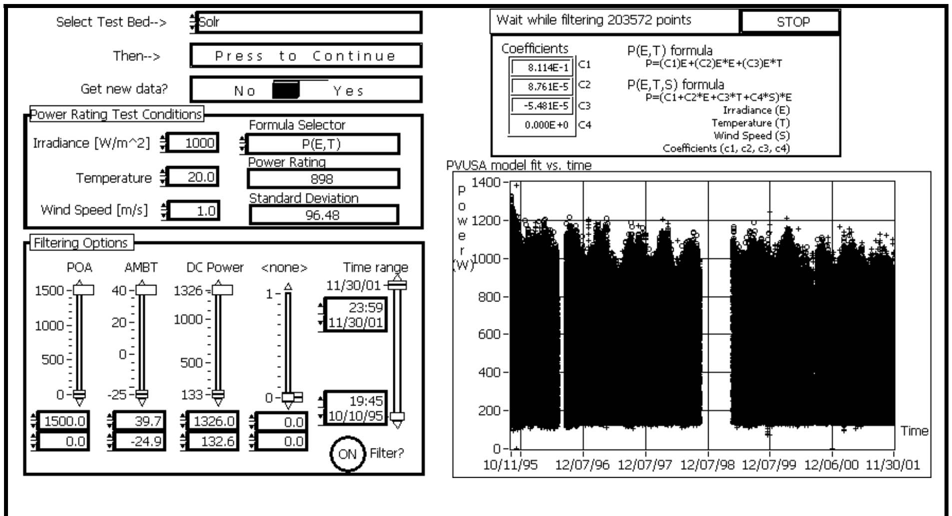

Figure 13a. SOLR unfiltered DC power.

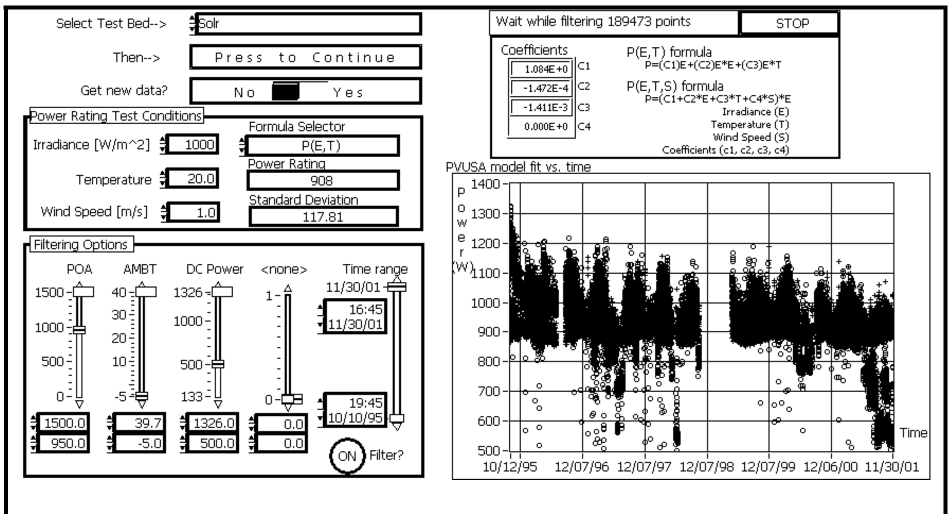

Figure 13b. SOLR filtered DC power.

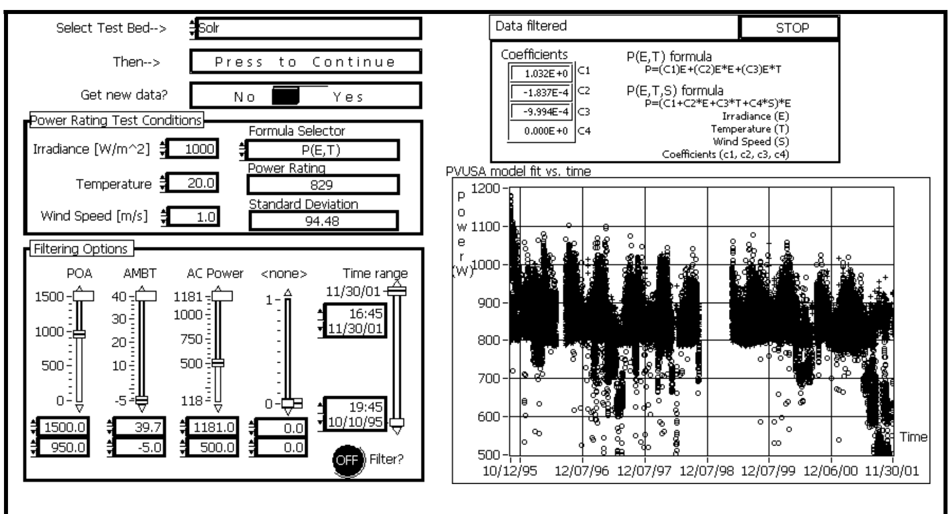

Figure 13c. SOLR filtered AC power.

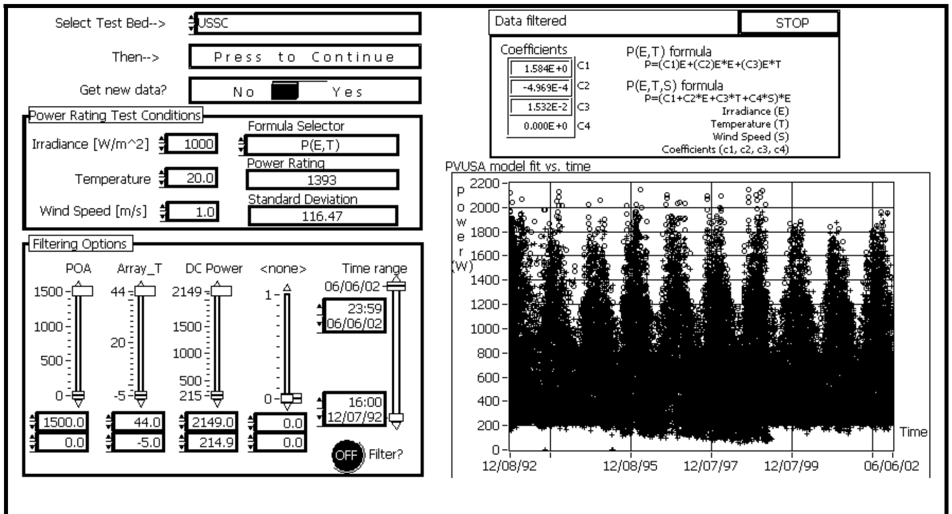

Figure 14a. USSC unfiltered DC power.

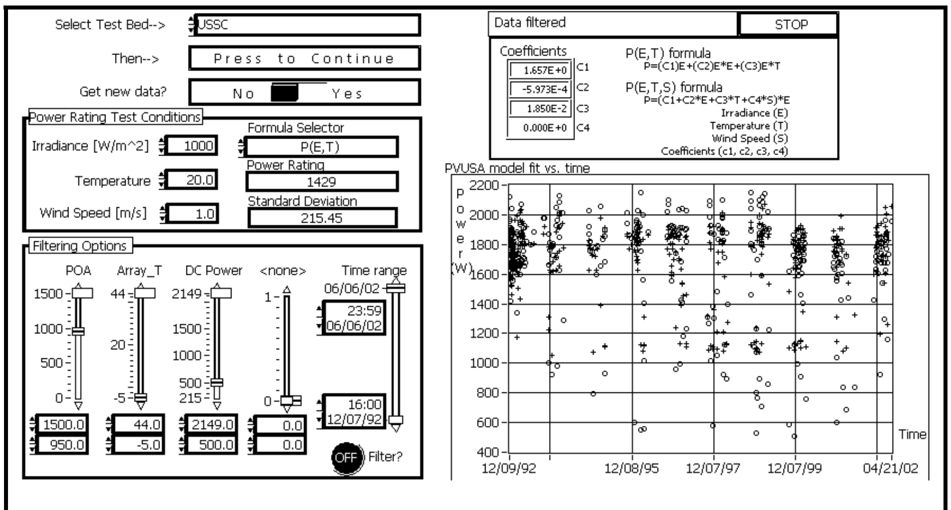

Figure 14b. USSC filtered DC power.

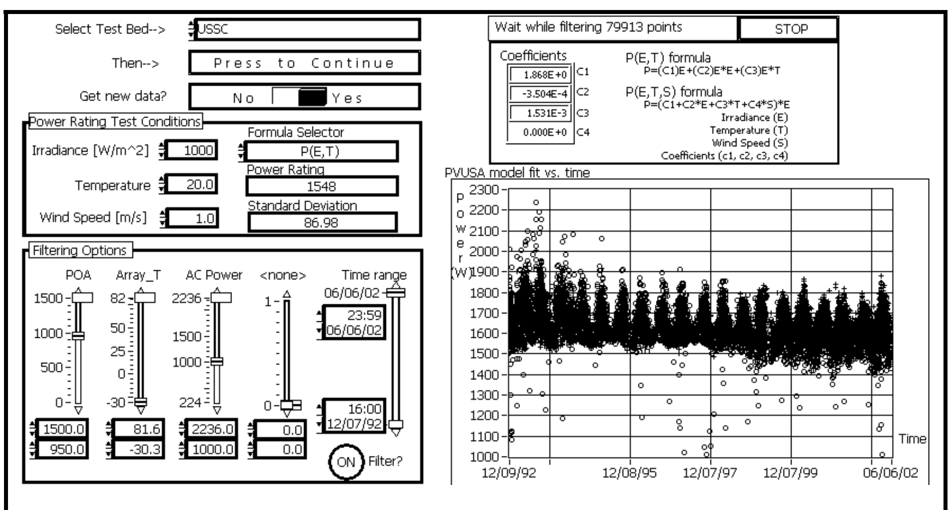

Figure 14c. USSC filtered AC power.

Appendix A. Data File Headers

APS 26 columns:

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
SYS_ID	YEAR	JDATE	TIME	DC_P	AC_P	POA	F20_POA	DC_V+	DC_V-
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
DC_A-	DC_A+	AC_V	AC_A	MT1	MT2	MT3	MT4	INV_T	AMB_T
20 U	**21 V**	**22 W**	**23 X**	**24 Y**	**25 Z**				
A_EFF	I_EFF	DCMWHR	ACMWHR	POAMWHR	20MWHR				

ASE 25 columns:

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
ID	Year	Day	Time	DC_P	AC_P	POA	DC_V	DC_I	AC_V
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
AC_I	M2_T1	M2_T2	M2_T3	M4_T1	M4_T2	M4_T3	M3_JBT	INV_T	Air_T
20 U	**21 V**	**22 W**	**23 X**	**24 Y**					
DC_EFF	INV_Eff	DCMWH	ACMWH	POAMWH					

CIS 27 columns until 05/24/2000 then changes to 28 Columns as shown below:

Pre-05/2000:

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
SYS_ID	YEAR	DATE	TIME	ARRAY_P	LOAD_P	POA	I1	I2	I3
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
V1	V2	V3	Max_I1	Max_I2	Max_I3	Load_V	T1	T2	T3
20 U	**21 V**	**22 W**	**23 X**	**24 Y**	**25 Z**	**26 AA**			
T4	Air_T	P1	P2	P3	DCMWh	POAMWh			

Post-05/2000

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
Sys_ID	Year	J_Day	Time	P_array	P_load	Irr_poa	I_array1	I_array2	I_array3
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
V_array1	V_array2	V_array3	I_max1	I_max2	I_max3	V_load	T_mod1	T_mod2	T_mod3
20 U	**21 V**	**22 W**	**23 X**	**24 Y**	**25 Z**	**26 AA**	**27 AB**		
T_mod4	T_air	P_array1	P_array2	P_array3	T_tcpl	En_dc	En_poa		

Roof 30 columns until 05/4/1998, then 27 columns until 10/22/1998, then 28 columns

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
SYS_ID	YEAR	Date	Time	DC_P	AC_P	POA	DCV+	DCV-	DCI-
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
DCI+	ACV	ACI	PAT1	PAT2	PAT3	NAT1	NAT2	NAT3	SATT1
20 U	**21 V**	**22 W**	**23 X**	**24 Y**	**25 Z**	**26 AA**	**27 AB**	**28 AC**	**29 AD**
SATT2	NATT1	INVT	ROOFT	AIRT	Array_Eff	INV_Eff	DCMWHr	ACMWHr	POAMWHr

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
ID	Year	Day	Time	POA	DC_Power	AC_Power	DC_V	DC_I	AC_V
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
AC_I	PAT1	PAT2	PAT3	NAT1	NAT2	NAT3	SATT1	SATT2	NATT3
20 U	**21 V**	**22 W**	**23 X**	**24 Y**	**25 Z**	**26 AA**			
INVT	RoofT	AMB_T	Array_Eff	INV_eff	21x_Temp	DAS_V			

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
ID	Year	Day	Time	POASRX	POA	DC_Power	AC_Power	DC_V	DC_I
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
AC_V	AC_I	PAT1	PAT2	PAT3	NAT1	NAT2	NAT3	SATT1	SATT2
20 U	**21 V**	**22 W**	**23 X**	**24 Y**	**25 Z**	**26 AA**	**27 AB**		
NATT3	INVT	RoofT	AMB_T	Array_Eff	INV_eff	21x_Temp	DAS_V		

Table 3. System data file headers.

SCI1 23 columns

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
SYS_ID	YEAR	J_DATE	TIME	DC_Power	AC_Power	POA_Irrad	DCV_POS	DCV_NEG	DCI_NEG
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
DCI_POS	ACV	ACI	Array_T1	Array_T2	Array_T3	Inv_T	Amb_T	Array_Eff	Inv_Eff
20 U	**21 V**	**22 W**							
DCMWhr	ACMWhr	POAMWhr							

SERF East 24 columns

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
ID	Year	Day	Time	DC_POW	AC_POW	POA_IRR	P_DCV	N_DCV	N_DCA
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
P_DCA	ACV	ACA	T1	T2	T3	Air_T	INVM_T	INVS_T	ARR_EFF
20 U	**21 V**	**22 W**	**23 X**						
INV_EFF	DCMWH	ACMWH	POAMWH						

SERF West 24 columns

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
ID	Year	Day	Time	DC_POW	AC_POW	POA_IRR	P_DCV	N_DCV	N_DCA
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
P_DCA	ACV	ACA	T1	T2	T3	Air_T	INVM_T	INVS_T	ARR_EFF
20 U	**21 V**	**22 W**	**23 X**						
INV_EFF	DCMWH	ACMWH	POAMWH						

SOLR 26 columns

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
SYS ID	Year	J_Date	Time	DC_Power	AC_Power	POA	DCV+	DCV-	DCI-
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
DCI+	ACV	ACI	PF	ACVA	MT1	MT2	MT3	MT4	INVT
20 U	**21 V**	**22 W**	**23 X**	**24 Y**	**25 Z**				
AMBT	EFF	Inv. EFF	DCPOW	ACPOW	POA Mhw				

USSC columns vary across many time periods, generally between 24 and 26 columns of data.

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
Sys_ID	YEAR	Day	Time	DC_P	AC_P	POA	DCV_+	DCV_-	DCI_+
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
DCI_-	ACV	ACI	Array_T	DAS_T	Encl_T	DC_Eff	AC_Eff	?	?
20 U	**21 V**	**22 W**	**23 X**	**24 Y**	**25 Z**				
?	?	?	?	?	?				

Entech 189 (OCIV Testbed)

0 A	**1 B**	**2 C**	**3 D**	**4 E**	**5 F**	**6 G**	**7 H**	**8 I**	**9 J**
Filename	Bogus Data	confidential	Manufacturer	Country	Sample ID	material	Pkg. Type	date	time (MST)
10 K	**11 L**	**12 M**	**13 N**	**14 O**	**15 P**	**16 Q**	**17 R**	**18 S**	**19 T**
E tot TB (W/m2)	area (cm2)	air temp TB (¡C)	Voc (V)	Isc (A)	FF (%)	Vmax (V)	Imax (A)	Pmax (W)	eff (%)
20 U	**21 V**	**22 W**	**23 X**	**24 Y**	**25 Z**	**26 AA**	**27 AB**	**28 AC**	**29 AD**
R @ Voc (½)	R @ Isc (½)	Jsc (mA/cm2)	ref device	ref CV (ma)	Source Spectrum	M used	Rpt Spectrum	comments	comments dir
30 AE	**31 AF**	**32 AG**	**33 AH**	**34 AI**	**35 AJ**	**36 AK**	**36 AL**	**37 AM**	**38 AN**
E.O.F Delim.	TB wind (m/s)	TB sensor 1	TB sensor 2	TB sensor 3	TB sensor 4	air mass	RMIS pressure (mB)	RMIS air (¡C)	RMIS wind (m/s)
39 AO	**40 AP**	**41 AQ**	**42 AR**	**43 AS**	**44 AT**	**AU**			
RMIS RH (%)	RMIS Dir (W/m2)	RMIS DH (W/m2)	RMIS GH (W/m2)	time sec since 1904	RMIS Glo norm (W/m2)	RMIS RH (%)			

Table 3 continued. System data file headers.